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Fertigation of muskmelons (Cucumis melo L.) and tomatoes (Lycopersicon esculentum Mill.)

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by

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GENERAL INTRODUCTION

Irrigation is essential for consistent high-quality vegetable production in Iowa. Drip or trickle irrigation applies water slowly, under low pressure, on a high frequency basis to the root zone of a crop. Drip irrigation is suited to central Iowa because many growers do not have enough acreage to justify the investment for the large well and pump necessary for overhead irrigation. But, they usually have access to a deep well with a flow rate which works well with drip irrigation.

One advantage of drip irrigation is the water savings which result from only wetting a portion of the crop root zone. This selective root wetting has been combined with fertilization to increase use efficiency. Some researchers have obtained higher crop yields using less total fertilizer by applying the fertilizer through the trickle irrigation system.

Fertilizers account for 42% of the energy used in vegetable production (34), making efficient fertilizer use economically important.

Much of the previous work with fertilization and trickle irrigation has been on soils with a low to medium cation exchange capacity (CEC) and a low organic matter content. Soils in central Iowa tend to have a relatively high CEC (17-25) and a high percentage of organic matter (3-6%). Soil characteristics influence nutrient action in the soil and may determine the success or failure of fertilization with trickle irrigation.

Muskmelons and tomatoes are two popular high-value crops which are widely grown in Iowa. The objectives of this research were to try to increase the use efficiency of nitrogen (N) and potassium (K) on muskmelons and tomatoes, respectively, by applying the nutrients through the trickle irrigation system, and to determine the optimum N or K rate for yield and quality on the heavier soils in central Iowa.

GENERAL LITERATURE REVIEW

Nutrient application with trickle irrigation

Trickle or drip irrigation is a method of applying water slowly, under low pressure on a high frequency basis to the root zone of a crop (44). Thus, large fluctuations in soil moisture and periods of plant water stress are often avoided (20). It may also be possible to avoid periods of crop nutrient stress by applying fertilizers through the trickle system at short intervals (40). Other reported advantages of applying nutrients with trickle irrigation include improved efficiency, labor savings and flexibility of timing nutrient application to crop demand (43). Although there are numerous reports of crops which have been successfully fertilized through a trickle irrigation system (9, 17, 22, 24, 30, 31, 32, 36, 37, 40, 41, 46), not all of the fertilizer elements are adapted to application with trickle irrigation.

Phosphorus (P) has been found to be unsuitable for application with trickle irrigation because it precipitates out near the trickle line shortly after application owing to its low soil water solubility (4, 16). But highly soluble and mobile elements such as N have been found to be more suitable for application with trickle irrigation (3).

When N in the ammonium form is applied with trickle irrigation, its initial soil movement will be influenced by the soil CEC (43). But, ammonium will be nitrified to nitrate within 2 to 3 weeks at soil temperatures in the 25°-30°C range, Nitrate is largely unaffected by the soil CEC and moves freely with the soil water, often concentrating on the periphery of the wetting zone (43). Miller et al. (30, 31) found that banded N moved between tomato crop rows out of reach of the roots when the trickle irrigation line was placed between the roots and the N band. But, when the tomatoes were furrow irrigated, the banded N near the plants moved into the crop row roots. To prevent N from becoming limiting when applied with trickle irrigation, the required N should be applied in several applications, according to the growth and development of the crop (17, 22, 30, 31, 40, 41).

An increase in N efficiency has resulted under some circumstances when N was applied with trickle irrigation (9, 17). Smith et al. (46) found that, for apple, peach, and sour cherry, the injection of N through the trickle system resulted in a 50% reduction in the amount of fertilizer needed compared to a broadcast application. They felt that the increase in efficiency resulted from localized N placement in the most actively growing portion of the tree roots.

Potassium has also been applied with trickle irrigation (16, 17, 22, 28, 36, 37, 50), but with less success than N. When the K ion reaches the soil, it quickly becomes adsorbed on to the cation exchange sites and movement only occurs once these sites are saturated. As a result, the movement of K is less than that of N. Some researchers have found K to move considerable distances when applied with trickle irrigation (23, 43), while others have reported limited movement (16, 17). The soil CEC will influence applied K movement. Munson and Nelson (33) reported that fine sands may lose up to 22 kg/ha of K under high fertilization rates (224-448 kg K/ha), while K leaching losses from fine textured soils, such as silt loams, at similar fertilization rates are practically zero.

There are reports of an increase in efficiency when K is applied with trickle irrigation. Uriu et al. (50), working with K deficient prunes on a clay loam, found that application of K with trickle irrigation corrected the deficiency and enhanced the leaf K level as compared to the grower practice of applying K in trenches and overhead irrigating. But, he also found that applying dry K near the trickle emitter resulted in the same leaf K status as injecting the K through the trickle system.

Nitrogen fertilization of muskmelons (*Cucumis melo*)

Nitrogen is essential to the growth and development of all plants. Worldwide, it is the element most often found limiting to crop yields. The N requirement of muskmelons has been investigated by several workers, often with conflicting results.

The N rate recommended for optimum yield depends on several factors. Lingle and Wright (27) reported yield responses with increasing N rates up to 134 kg N/ha. This rate could be reduced if large amounts of soil residual N were present. But, more than 134 kg N/ha would be necessary if the soil contained a small amount of organic matter and/or a high percentage of sand. Wilcox (54) found that optimum plant growth and muskmelon yield occurred with a 5-year mean preplant application of 80-90 kg N/ha on a fine sandy loam. He stressed the importance of a readily soluble form of N in order to supply large amounts of N early during the growth and development period. Bradley et al. (6), working with four soil types (fine sandy loam, fine sand, silt loam and a sandy loam in Arkansas), did not find a significant response to N on muskmelons. But, they felt that 67-101 kg N/ha would ensure optimum yield under most conditions. Flocker et al. (12)

found that muskmelon yield responses on a clay loam above 34 kg N/ha depended largely on the previous cropping history of the field.

Nitrogen application recommendations based on tissue analysis also differ. Pew and Gardner (39) established fertilization guidelines for muskmelons growing in Arizona based on petiole NO_3-N levels. They found that visual deficiency symptoms occurred when the petiole NO_3-N levels dropped below 4,000 ppm at any growth stage. Lingle and Wright (27) reported that, if the petiole NO_3-N level at the 6-8 true leaf stage dropped below 5,000 ppm, then an additional N application would be necessary for optimum yield. Wilcox (54) found that optimum melon yields were obtained when total leaf blade N was over 4.5% or when petiole NO_3-N was above 15,000 ppm during vegetative growth and fruit initiation stages.

Fruit quality parameters are also affected by N. Flocker et al. (12) observed a decrease in fruit size when N was less than that needed for optimum yield. They also found that increasing the N rate above that needed for optimum yield stimulated vine growth, enhancing the number of cull melons. Pew and Gardner (39) found that N had little effect on melon size, earliness or storage quality. Deficient levels of N did result in lower netting, poorer general appearance and an increase in the number of cull melons. Soluble solids have not been correlated to N rates (6, 39, 47), except with soluble solids from melons growing in a very N-deficient situation which resulted in low soluble solids readings were compared to melons grown with sufficient N.

There are few reports of N application to muskmelons with trickle irrigation. Shmueli and Goldberg (45) compared the effect of irrigation methods on melon yield. When trickle irrigation was used, N was injected into the system in place of normal sidedressings, but different N rates were not compared. Dan (11) could find no effect of trickle injected N on melon yield with calcerous silty loam or a calcerous silty clay soil types. The only N effect was a slight enlargement in fruit size.

Potassium fertilization of tomatoes

Tomatoes are heavy K users. The fruit of a 65 mt/ha crop will remove approximately 130 kg/ha of K (26). Less than an optimum K level results in a reduction in both fruit yield and quality.

Soil testing is a reliable method of predicting the need for supplemental K on tomatoes. Illinois recommendations (15) call for between 54 and 326 kg K/ha on loam soil types, the specific amount being dependent on the exchangeable K present as measured by the ammonium acetate soil test. Wilcox (53) reported a 30% yield response when 218 kg K/ha was applied to a silt loam which had 112-168 kg/ha of exchangeable K. Numerous other reports discuss the optimum K rate in relation to plant population and spacing (48, 51), once-over mechanical harvesting (2), and the use of different irrigation methods and plastic mulches (38).

One of the largest factors influencing applied K availability is soil type. Munson and Nelson (33) reviewed the literature on K movement and stress the importance of K sidedressing on light textured soils.

Potassium application recommendations to achieve maximum yield and quality have also been based on leaf analysis. But, differences in the leaf K concentration between cultivars growing under identical conditions can make broad guidelines difficult to establish. Bergman (5) found tomato leaf percentages ranging from 2.37-3.36% in six tomato cultivars growing side by side in Pennsylvania. Lingle and Lorenz (26) reported K deficiency symptoms on the determinate machine-harvested cultivars VF-145 and VF-13L when older indeterminate and semideterminate cultivars showed ample K. Widders and Lorenz (52) attributed this to the determinate cultivars' small root system and concentrated fruit set. Tomato fruits are strong sinks for K; the determinate cultivars' concentrated fruit set causes massive translocation out of the leaves resulting in deficiency symptoms. On the other hand, semideterminate cultivars have a lower fruit-to-shoot ratio, which enables them to maintain root growth during fruit development. The increased absorbtive capacity of the semideterminate roots establishes more reserve K in the vegetative tissue, preventing K stress during fruit development and ripening.

Added K affects fruit quality in several ways. Increasing the K level has been found to improve red color (1, 25). Trudell and Ozbun (49), using sand cultures, found that increasing the soil solution K concentration raised the level of most fruit carotenoids and greatly increased the level of lycopene in ripe fruit.

Blotchy ripening is a serious disorder of ripe fruit characterized by white pericarp tissue which is also affected by K (19, 35). Ozbun et al. (35) found that blotchy ripening could be induced or eliminated by decreasing or increasing, respectively, the soil K level. Collin and Cline (8) attributed white wall tissue and green shoulders to a low K supply, light injury (due to the addition of supplementary light) or an interaction of K and light. They induced blotch and vascular browning by replacing the K with calcium (Ca) or sodium (Na) in nutrient solutions. Forster (14) demonstrated how green shoulders could be reduced and almost eliminated in water cultures by increasing the K supply.

Several studies have been conducted to evaluate fertilizer application to tomatoes with trickle irrigation (23, 28, 36, 37, 38). Potassium was included as one of several elements in these investigations. Most of the work was done on low fertility, sandy soils on which the productivity was limited by low nutrient concentration in the root zone. Nutrient application through the trickle system often enhanced yields over broadcast or band applied fertilizer, but the design of the investigations makes it difficult to separate out the effect of potassium from that of the other applied elements.

SECTION I. EFFECT OF NITROGEN RATE AND METHOD OF APPLICATION ON MUSKMELON (*Cucumis melo* L.) YIELD AND QUALITY

INTRODUCTION

Fertilizers account for 42% of the energy used in vegetable production (34) and, thus, represent a considerable portion of most vegetable growers' variable expenses. One efficient fertilizer application technique is injection through the trickle irrigation system (9, 17, 46, 50). Advantages of this application technique include labor and energy savings and flexibility of timing nutrient application to crop demand (43, 44).

Elements which become insoluble or are tightly adsorbed on soil colloids are not desirable for application with trickle irrigation (4, 16). But, highly soluble elements, such as N, have been applied successfully (9, 17, 43, 46), sometimes giving the same yield with a 50% reduction over the broadcast N rate (46).

Muskmelons are a popular fresh-market crop in Iowa, and the N rate recommended for optimum yield ranges from 34-120 kg/ha (6, 12, 27, 53); the specific amount is dependent on soil type and the previous cropping history of the field (12, 27).

Guidelines for muskmelon fertilization have been developed using tissue analysis. Pew and Gardner (39) reported yield reductions if petiole NO_3-N levels dropped below 4,000 ppm at any growth stage. Wilcox (54) found that optimum yield occurred when petiole NO_3-N was above 15,000 during vegetative growth and fruit initiation stages, while Lingle and Wright (27) reported that, at the 6-8 true leaf stage, NO_3-N below 5,000 ppm resulted in reduced yield.

Fruit quality parameters are also affected by N. Less than an optimum N level has decreased fruit size, reduced netting, resulted in poorer general appearance, increased the number of cull melons and, in some cases, caused a decrease in soluble solids (12, 27, 39).

The purpose of this study was to determine the optimum N rate for muskmelon yield and quality grown with clear plastic mulch and trickle irrigation, and to compare the efficiency of N applied either preplant broadcast or injected through the trickle system.

PROCEDURES

The experiment was conducted on a central Iowa sandy loam soil with 1.5% organic matter, a CEC of 10 meq/100 grams, 280 kg/ha of exchangeable K and P of 50 kg/ha. The previous crop was annual rye. Phosphorus and K were applied broadcast preplant according to soil test recommendations. Bensulide and chloramben were used for weed supression along with normal pest management practices for insect and disease control. Trickle irrigation tubing was knifed 5 cm deep, 20 cm off the row center at the same time 92-cm wide clear plastic mulch was laid.

Muskmelons (*Cucumis melo* cv. Burpee Hybrid) were seeded in 5.7 cm peat pots and transplanted through the clear plastic mulch on May 22, 1981. Individual plots consisted of single rows 9.1 m long and 1.8 m wide with plants spaced 60 cm apart in the row.

Treatments consisted of 4 N rates (45, 90, 135 and 180 kg N/ha) and two N application methods arranged in a randomized factorial design with 4 blocks. The two application methods were: 1) the entire N rate applied broadcast preplant under the plastic strip, or 2) the entire N rate injected through the trickle system according to crop growth and development.

The N source for the experiment was Uran, a liquid fertilizer with an analysis of 28-0-0. Beginning June 1, equal injections were made twice a week with 2/3 of the total rate applied during the first 3 weeks of June and the remaining 1/3 applied during the end of June until July 27. Injections were made by dissolving the fertilizer for each treatment in 3 liters of water and pumping the solution into the operating trickle irrigation system. Each injection lasted approximately 15 minutes. Following injection, the trickle system was operated for at least 45 minutes.

Harvest began when the melons reached the full slip stage. During each harvest, fruit were separated into marketable or culls. Culls were fruit with poor netting, growth cracks, small in size and/or misshapen. Early marketable yield was fruit production between August 3 and August 15 and would correspond to the period in which a grower would receive the highest market price. On the last harvest date, August 28, all the remaining immature fruit were harvested, weighed and counted. Total yield was a combination of total marketable and total cull weight plus the weight of the immature green fruit from August 3 to August 28. Total fruit set was the number of melons, both mature and immature, produced by a treatment.

During the single largest harvest, soluble solids, flesh thickness, cavity length and diameter, and melon length and diameter were determined. The melon diameter and length were combined into a diameter-to-length ratio to give an indication of fruit shape. Soluble solids were determined by placing the melons ground-side down, taking a 2-cm plug from the stem end at the 1 o'clock position, and measuring the percent sugars of the flesh juices with a refractometer.

To determine the N status of the plants, approximately 30 of the most recently matured petioles (the 5th to 6th leaf from the vine tip) were sampled from each plot on June 22, July 13 and August 3. Petioles were dried in a forced air oven at 70°C for at least 72 hours, then ground in a Wiley mill to pass a 40-mesh screen. Nitrate nitrogen concentration was determined with a nitrate ion specific electrode.

Statistical analysis, using analysis of variance and general linear model procedures, measured the effects of the N rate and application method on the response variables.

RESULTS

Fruit yield

There were no interactions between the N rate and application method for any yield variable measured (Table A1). Neither early nor total yield was affected by the N rate (Table 1, A1); however, most yield parameters did show a yield increase over the zero rate at the first N increment. The zero rate was not part of the treatment design and could not be included in the statistical analysis.

Although melon yield was not influenced by the N rate, applying the N broadcast preplant was superior to injecting the N through the trickle system (Table 1). Early marketable yield ($P>0.07$) was increased 19% (Table 1) and total marketable yield ($P>0.06$) was increased 14% (Figure 1, Table 1) by broadcasting all of the N rather than applying the N through the trickle system. There was no effect of the N application method or rate on fruit size, green fruit production, or cull yield (Tables 1, A1). The number of fruit produced per plot was not affected by the N rate, but was affected by the application method ($P>0.03$); an average of 6 more fruit were produced on plots having N applied broadcast preplant rather than injected through the trickle system.

Fruit quality

The ratio of the external melon diameter to length, cavity length, cavity diameter, flesh thickness and soluble solids was measured as an indication of melon quality.

Table 1. Effect of N rate and application method on 'Burpee Hybrid' muskmelon yield, 1981

	Early yield		Total yield				Marketable fruit weight	Fruit number per plot
Treatment	Marketable	Culls	Marketable	Culls	Green fruit[a]	Total		
N rate kg/ha	Mt/ha						kg/fruit	
Check,[b] 0	10.7	1.8	28.2	14.5	13.2	55.9	2.40	52
45	28.7	6.9	38.3	11.5	7.0	55.9	2.35	55
90	28.6	7.7	34.5	15.1	5.6	54.5	2.42	50
135	25.4	7.6	32.2	15.1	7.4	53.6	2.37	52
180	29.8	8.7	40.0	15.2	5.9	59.4	2.31	58
Appl. method								
All broadcast	30.8	7.5	38.6	13.9	6.6	58.3	2.35	57
All injected	25.4	8.0	33.4	14.5	6.3	53.4	2.37	51
Prob >F	.07	.64	.06	.58	.76	.09	.09	.03

[a]Immature green fruit at last harvest date, August 28, 1981.

[b]The check or zero rate was not part of the statistical design.

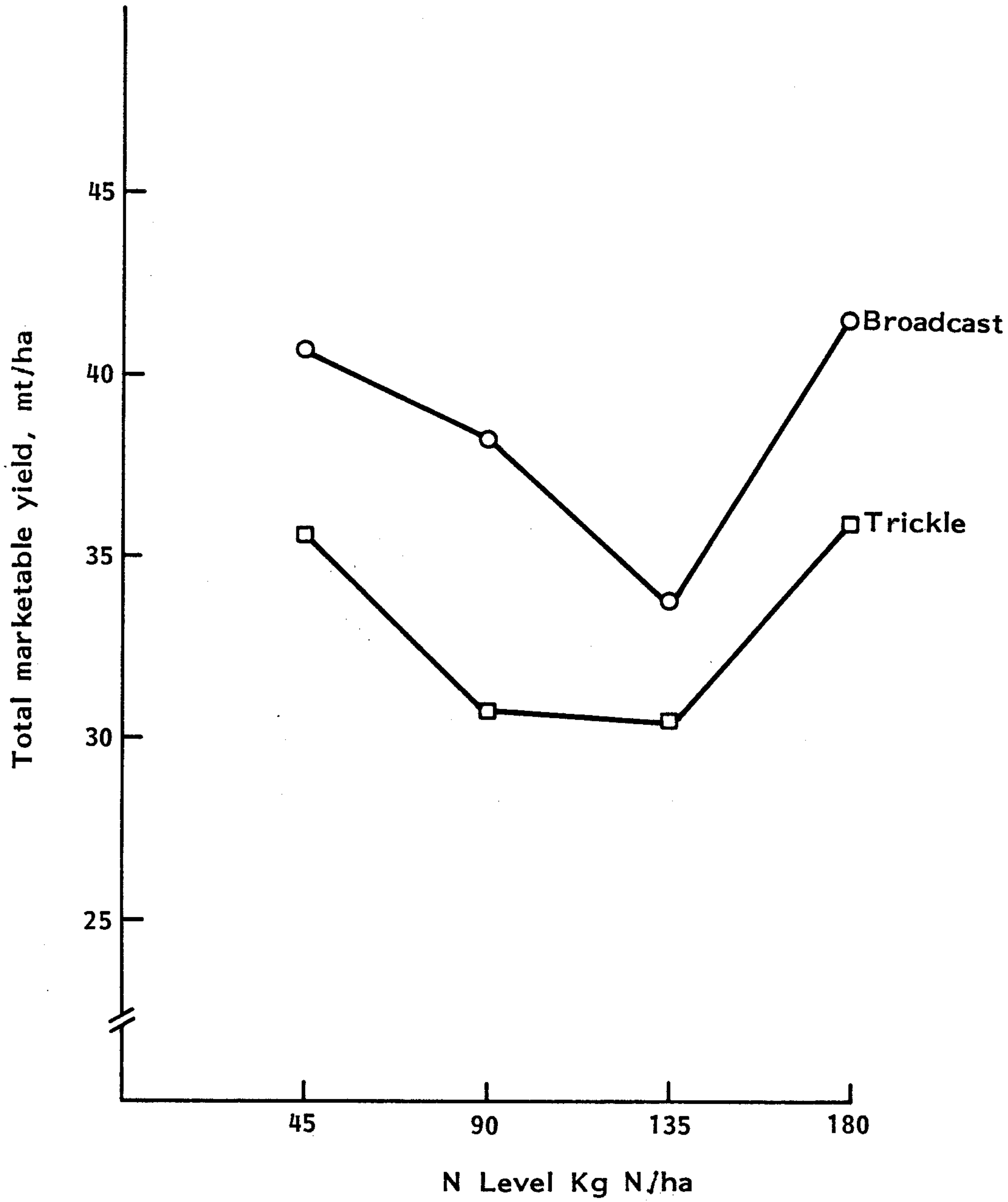


Figure 1. Effect of N rate and application method on muskmelon total marketable yield, August 3 to 28, 1981

Soluble solids (Table A2, Figure 2) displayed a significant interaction between the N rate and application method. This interaction is significant because of a relatively high soluble solids reading (7.4%) when the N is applied through the trickle system at the 90 kg N/ha rate and a corresponding low reading (6.3%) at the same rate when N was applied preplant.

There was no effect of the treatments on external shape of internal cavity width or length (Table 2).

Flesh thickness (Tables 2, A2) showed a significant N response; an increase in the N rate resulted in a decrease in flesh thickness of approximately 3 mm.

Table 2. 'Burpee Hybrid" flesh width, cavity length, cavity width, and external width/length ratio as affected by the N rate and application method

Treatment	External width/length	—Internal cavity— Width	Length	Flesh thickness (cm)
N rate kg/ha				
Zero rate	.97	8.4	11.7	3.9
45	.96	7.7	10.5	3.9
90	.97	8.2	11.2	3.9
135	.99	7.9	10.5	3.7
180	.97	8.4	10.7	3.6
Prob. >F	.24	.24	.45	L, .04
N application method				
Broadcast preplant	.97	8.0	10.9	3.8
Injected	.97	8.1	10.6	3.7

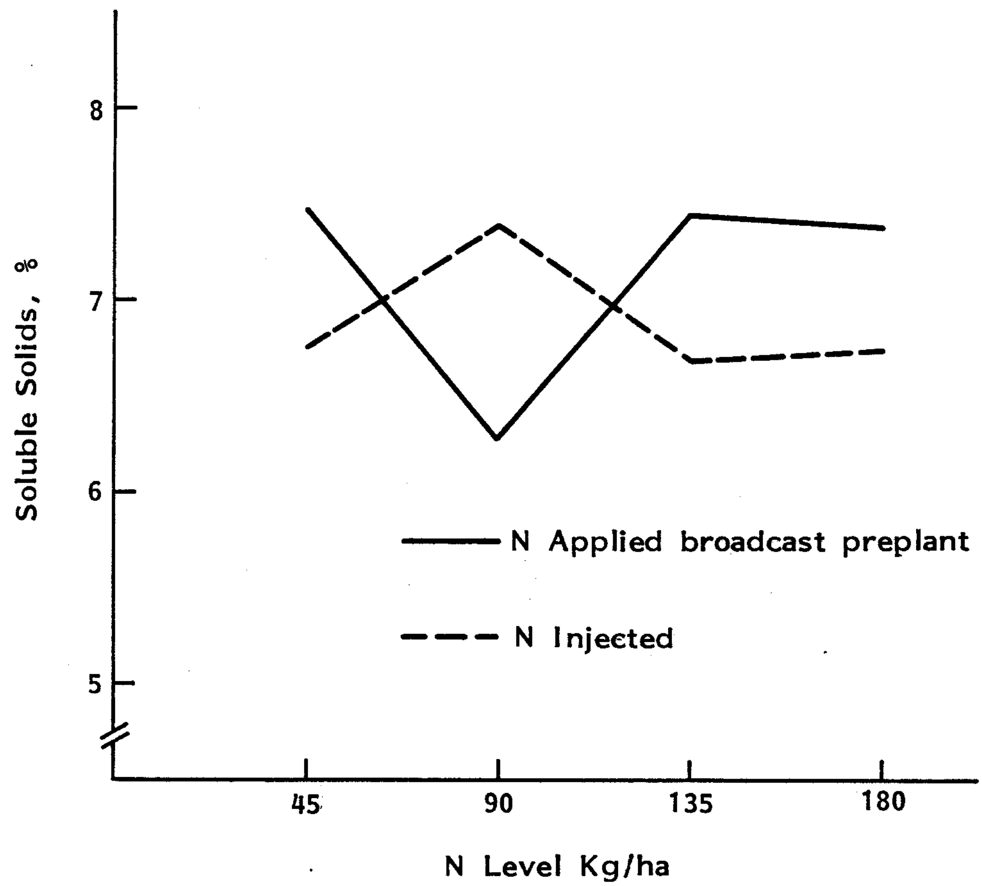


Figure 2. Effect of N rate and application method on muskmelon marketable fruit soluble solids content, 1981

<u>Petiole NO_3-N concentration</u>

Petiole NO_3-N levels showed a significant response to the N rate on all sampling dates and to the application method on June 22 and July 13 (Table A3, Figures 3, 4, 5). Injection of N into the trickle system was superior ($P>0.04$) to broadcast preplant N in terms of plant NO_3-N concentration early in the growing season (Figure 3), but inferior as the season progressed (Figures 4, 5).

Overall, at the 45 kg N/ha rate, petiole NO_3-N levels were high, 24,000 ppm, at the beginning of the growing season and then decreased to 500 ppm as the growing season progressed through harvest (Figure 6).

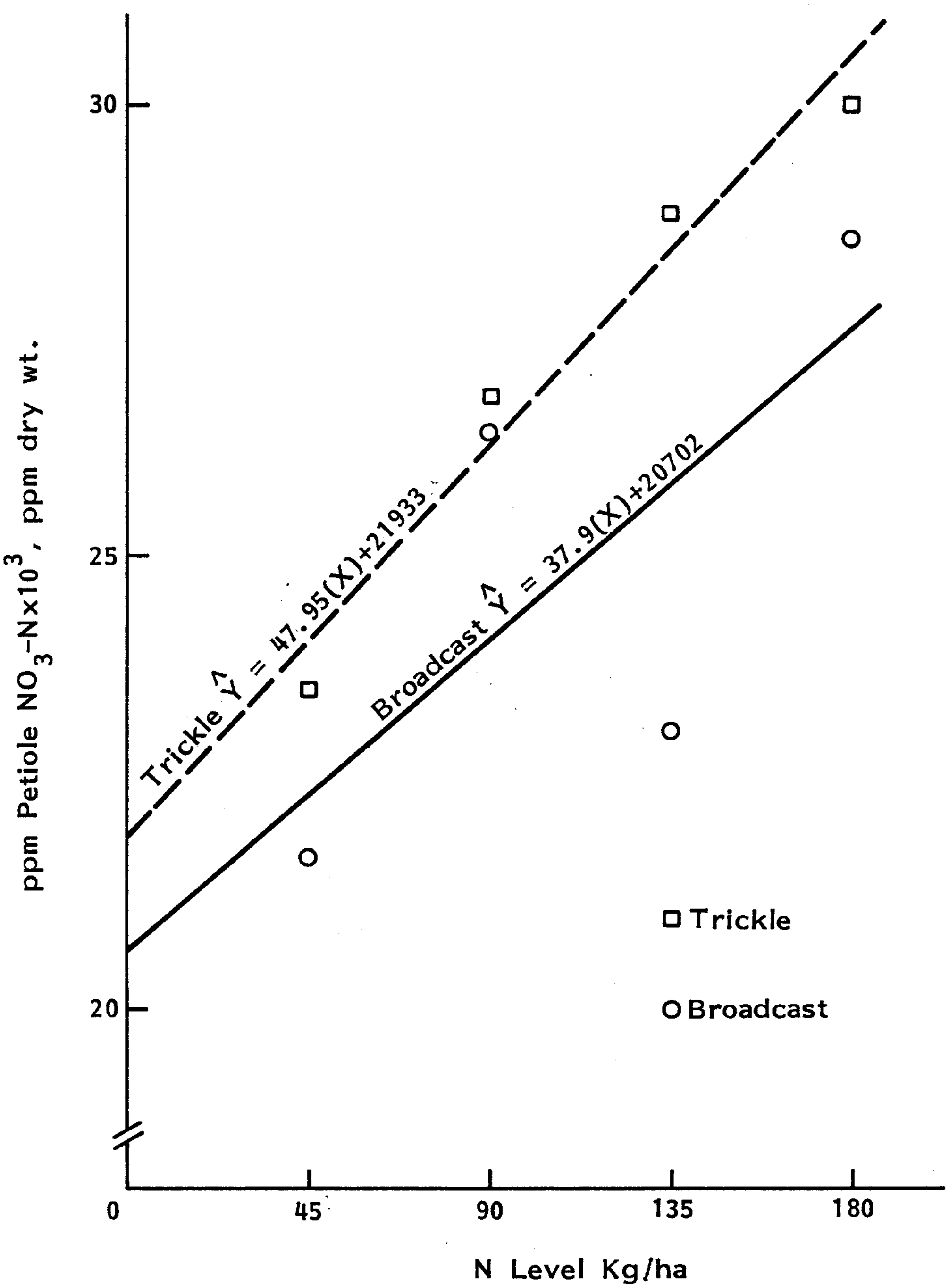
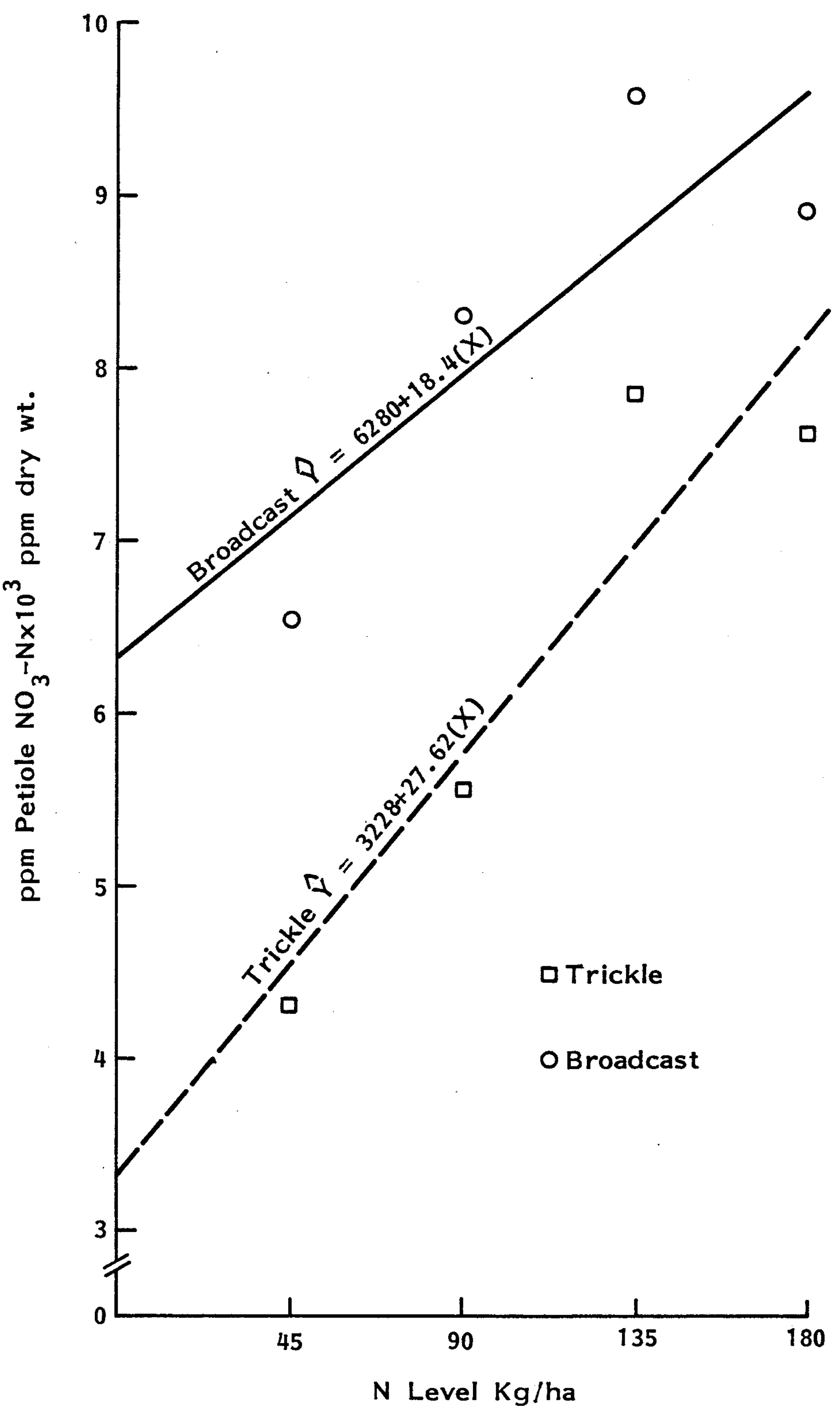


Figure 3. Effect of N rate and application method on muskmelon leaf petiole nitrate concentrations on June 22, 1981


10
9
8
7
6
5
4
3
0
ppm Petiole NO_3^--N x 10^3 ppm dry wt.
Broadcast $\hat{Y}$ = 6280+18.4(X)
Trickle $\hat{Y}$ = 3228+27.62(X)
Trickle
Broadcast
45
90
135
180
N Level Kg/ha

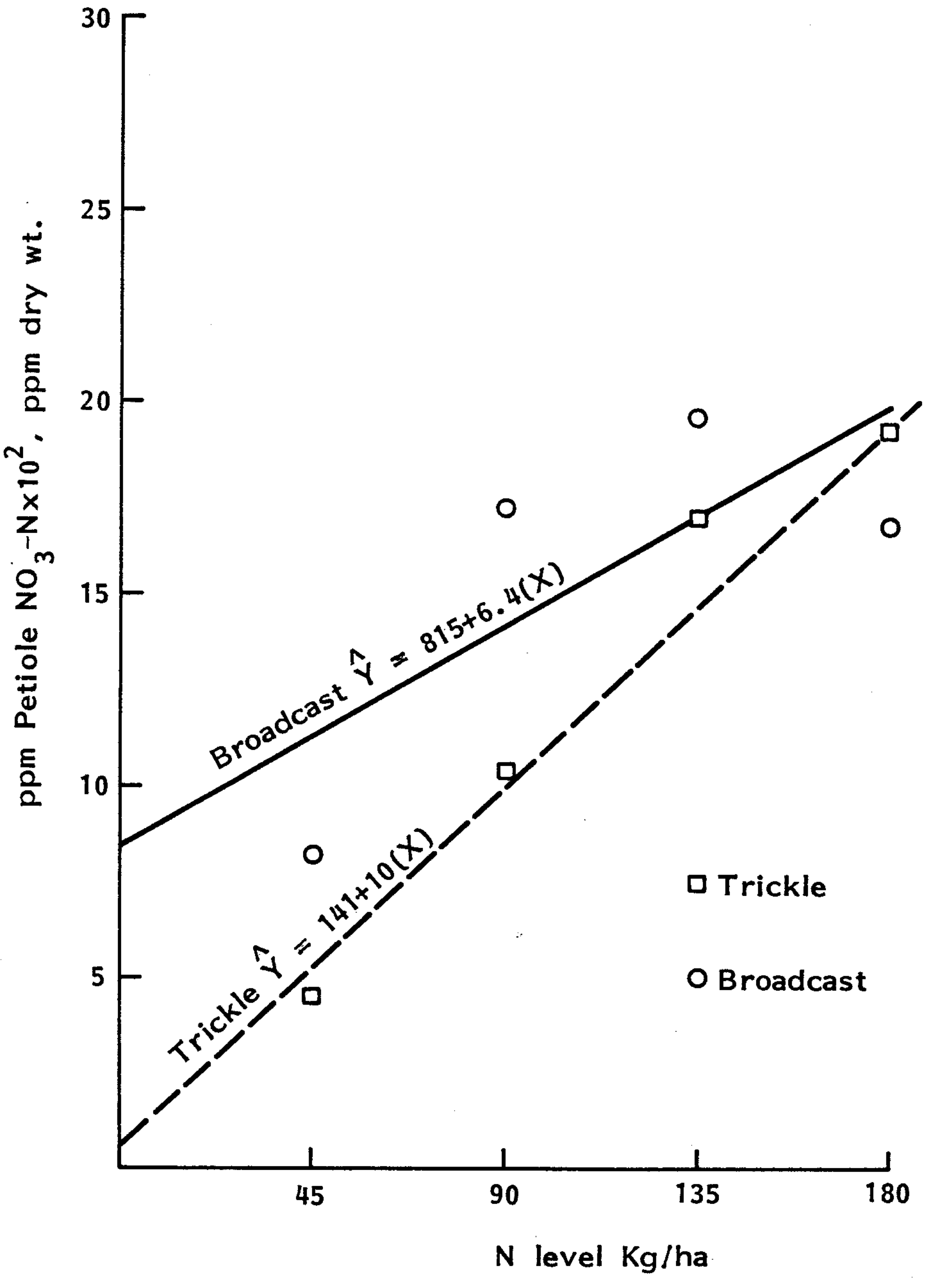
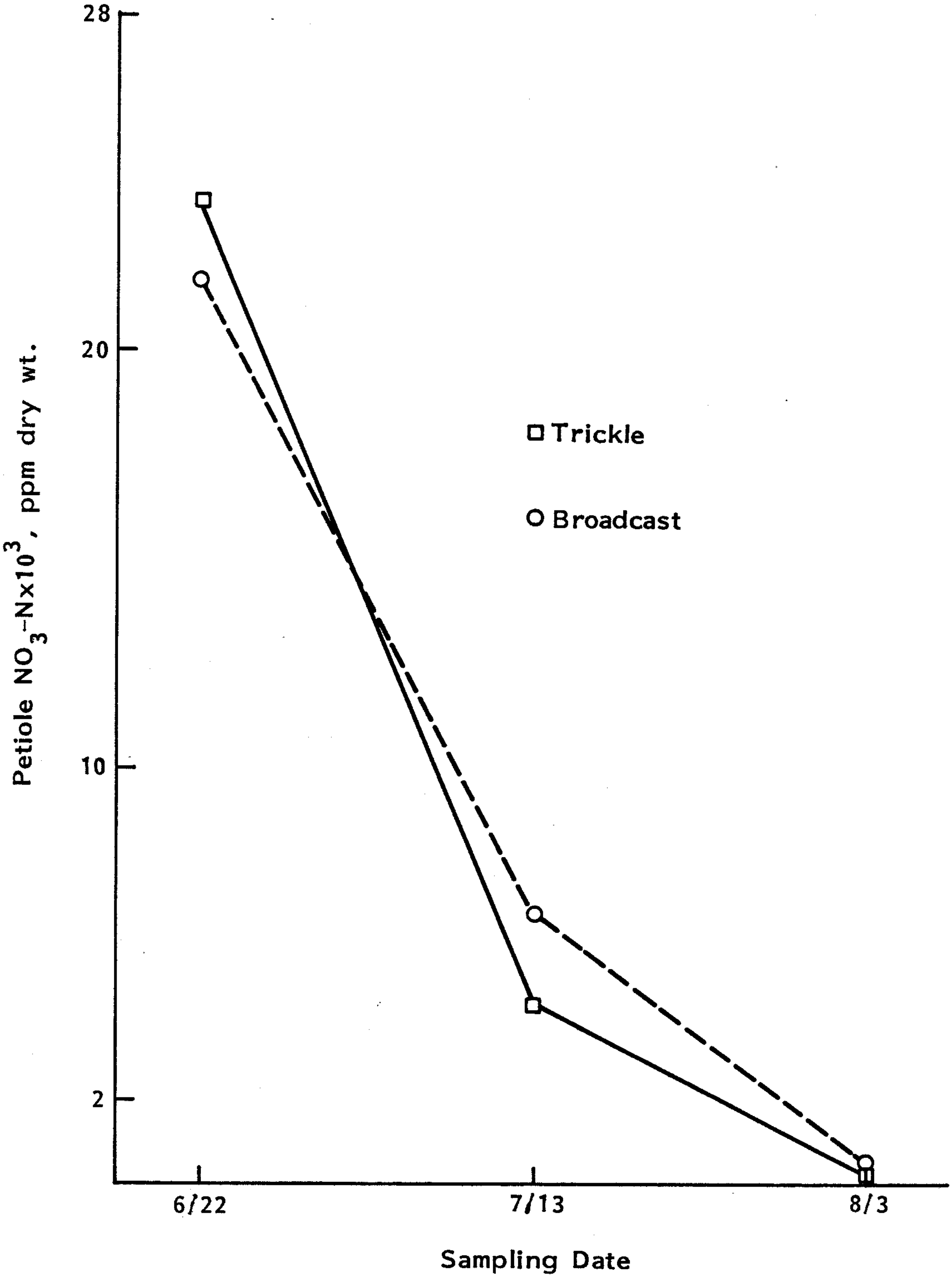


Figure 5. Effect of N rate and application method on muskmelon leaf petiole nitrate concentration on August 3, 1981


28
20
10
2
Petiole NO_3-N$\times10^3$, ppm dry wt.
Trickle
Broadcast
6/22
7/13
8/3
Sampling Date

DISCUSSION

Nitrogen application recommendations for maximum muskmelon yield in melon growing regions of the country are generally in the 112 kg N/ha range (15, 27). A zero or check rate was not part of this treatment design. But zero rates were present in nearby plots and the 45 kg N/ha rate does show a 36% increase for total marketable yield as compared to the zero rate. But, once above the 45 kg N/ha rate, there is no further yield response. The lack of a yield response in this experiment can best be explained by the petiole NO_3-N levels. Wilcox (54), Pew and Gardnew (39), and Lingle and Wright (27) recommended critical NO_3-N levels of 15,000, 22,000 and 8,000 ppm, respectively, early in the growing season. It is apparent (Figure 6) that the petiole NO_3-N levels and, thus, the plant N status early in the growing season were above these suggested critical levels. Forty-five kg N/ha normally would not be considered sufficient for maximum muskmelon yield, but three factors may have allowed this low rate to be adequate. First, plastic mulch was used, which has been shown to reduce N leaching losses (7, 10), thus reducing the applied N rate needed for maximum yield. Second, an unusually dry winter and spring probably prevented the leaching of residual N, allowing more N than usual to remain in the root zone. This can be seen on the first sampling date (Figure 3) on which the petiole NO_3-N difference between the 45 and 180 kg N/ha rate is only 8,000 ppm, whereas Wilcox (54) reported an almost 15,000 ppm NO_3-N difference between the 50 and 150 kg N/ha rate on melons growing in Indiana. Thirdly, the soil contained approximately 1.5% organic matter along with a previous cover crop of annual rye, which, through mineralization, released additional N.

Early marketable yield was increased 5.4 mt/ha, total marketable yield was increased by 5.2 mt/ha, and an average of six more melons were produced per plot by broadcasting the N as compared with N injection through the trickle system. Enhanced early yield from broadcast application, as compared to injection, was responsible for the significant increase in total marketable production. This broadcast N effect was probably on crown flower production and/or crown fruit set. Based on this work, applying the N broadcast preplant under the plastic mulch is superior to injection in terms of yield, even though the early season plant N status is improved by injection.

The effects of N reported in the literature on melon size and netting were not observed in this investigation, probably due to an adequate N level on all treatments.

Soluble solids show a significant interaction between the N application method and the N rate. At the 45, 135, and 180 kg N/ha rates, broadcast N causes a slightly higher soluble solids reading. But, at the 90 kg N/ha rate, this situation is reversed, resulting in a significant interaction. This is probably the result of random chance, as no consistent main effects seem to be influencing soluble solids. Thus, consistent with other work (6, 39), soluble solids do not seem to be affected by the N rate or application method. Overall, soluble solids readings were low; sugar percentages above 11% are considered necessary for high quality melons. Cool, cloudy weather during the harvest period may have contributed to the overall low soluble solids readings.

Flesh thickness shows a significant response to the N rate. With increasing N levels, there seems to be a corresponding decrease in flesh thickness. The flesh thickness difference between the high and low N rates is only 0.3 cm. This would seem to have little, if any, economic significance.

Overall, the NO_3-N concentration in the muskmelons followed patterns reported by other research workers (39, 54), with high NO_3-N levels ranging from 21,000 to 29,000 ppm early in the growing season, then decreasing levels to between 500 and 1500 ppm as growth and development progressed. Although most yield parameters were not affected by the N rates, there was a significant linear uptake of applied N with increasing N rates. Only on June 22 is trickle applied N superior to applying the N broadcast preplant. After the onset of fruit set (end of June to July 10), the trend is for all broadcast N to be superior in supplying the plant with N. Miller et al. (30, 31) found banded N moved to the edge of the trickle wetting pattern and, thus, away from the plant roots; but, when the N was applied in the trickle system, there was always adequate N available to the plant roots. The increase in efficiency which resulted for injected N on the first sampling date disappears later in the growing season. The melon root system expanded laterally as the growing season progressed and may have come in contact with N previously moved out of reach by trickle wetting pattern.

A possible strategy for maximum fruit set and melon yield might be to take advantage of the increase in efficiency of injected N early in the growing season, but, also, to take advantage of the trickle wetting pattern's ability to move N out of the root zone. For instance, Stark and Haut (47) found that N was needed in large amounts early in the melon's growth and development. But, once fruit set began, the N should be depleted for maximum yield. A high N status could be achieved early for maximum vegetative growth, followed by low N during fruit set. The low N status could be induced by trickle irrigating frequently, removing N from the root zone, especially on the soil types used in this experiment.

When trickle irrigation is used with melons, it may be advisable to apply the majority of the N preplant, but also apply a small amount through the trickle system early in the plant's development. This would ensure maximum N availability for the entire growing season.

Coarse-textured soils, which often have very low N concentrations, may benefit more from N applications through the trickle system. But, on heavier soils, such as the ones used in this experiment, a high N status early in the growing season is easy to achieve with broadcast N, especially when plastic mulch is used.

SECTION II. EFFECTS OF POTASSIUM RATE AND METHOD OF APPLICATION ON TOMATO (*Lycopersicon esculentum* MILL.) YIELD AND QUALITY

INTRODUCTION

Fertilizer crop use is influenced by nutrient placement, timing, application method and irrigation. Fertilizers account for 42% of the energy used in vegetable production (34), making efficient fertilizer use economically important.

One fertilizer application technique which has been found to increase nutrient efficiency is by injection of the nutrients through the trickle irrigation system (9, 17, 46). Trickle irrigation wets a portion of the crop root zone. When fertilizers are applied with trickle irrigation, they tend to stay within the crop root zone, sometimes giving an increase in use efficiency.

Not all elements are adapted to application with trickle irrigation. Potassium is readily adsorbed on to the soil cation exchange sites and movement can be limited (16), except on low CEC, sandy soils where K movement following application with trickle irrigation has approached that of N (23).

Potassium application with trickle irrigation has resulted in an increase in K uptake and efficiency over preplant broadcast. Uriu et al. (50) found that K application to prune trees through trickle irrigation was superior to applying the K in trenches and supplying water with overhead irrigation. But, applying dry K, on the soil surface near the trickle emitter, was found to be as effective in injecting the K through the trickle system, thus indicating that trickle irrigation was responsible for the improved K uptake. Goode et al. (17) compared broadcast and trickle injected K on apples. He reported that injected K generally resulted in a higher K leaf status than broadcast K.

Tomatoes are heavy K users. The fruit of a 65 mt/ha crop will remove approximately 130 kg K/ha (26). Less than an optimum K level results in reduced fruit yield (1, 25, 35, 53, 55) and quality. Correcting a K deficiency increases quality by increasing red color (1, 25, 35), reducing or eliminating blotchy ripening (8, 19) and decreasing the severity of or eliminating green shoulders (14).

Potassium application recommendations to achieve maximum yield and quality have also been based on leaf tissue analysis (21, 41, 53). But, differences in leaf K concentrations between cultivars growing under identical growing conditions can make specific guidelines difficult to establish. Lingle and Lorenz (26) reported K deficiency symptoms on determinate, machine-harvested cultivars VF-145 and VF-13L, when indeterminate, hand-harvested cultivars showed ample K. Supporting these findings, Bergman (5) found K percentages ranging from 2.37 to 3.36 in 6 tomato cultivars treated identically in Pennsylvania.

There are several reports of successful K application to tomatoes with trickle irrigation. But, other elements were also injected through the trickle system, making it difficult to determine the effect of the trickle applied K from the other applied elements (3, 23, 28, 36, 37).

The purpose of this study was to determine the optimum K rate and K application method, either broadcast preplant or injected through the trickle system, for tomato yield and quality.

PROCEDURES

The experiment was conducted on a central Iowa loam soil with 3.0% organic matter, pH of 6.0, exchangeable K of 147 kg/ha (low-medium) and P of 22 kg/ha (low). Adequate P and 68 kg/ha of N were applied broadcast preplant according to soil test recommendations. Trifluralin was used for weed supression and standard pest management practices were used for insect and disease control.

Tomatoes (cv. Pik Red), an early determinate cultivar, were planted in the greenhouse on April 1, 1981, in 5.7 cm peat pots and transplanted into the field on May 9, 1981. Individual plots consisted of single rows 6.1 meters long with 1.4 meters between rows and plants spaced 61 cm apart in the row. A border row was used between each plot.

Treatments consisted of 4 K levels (56, 112, 224, and 896 kg/ha) and two K application methods arranged in a randomized factorial design with four blocks. The two application methods were: 1) the entire K rate applied broadcast preplant and rototilled to a depth of 15 cm; or 2) 1/2 the K rate broadcast preplant and rototilled to a depth of 15 cm and 1/2 injected through the trickle system according to vegetative development. Potassium chloride (as 0-0-60) was used to supply the broadcast K, while both potassium nitrate (as 14-0-48) and potassium chloride were used to supply the injected K. Nitrogen was equalized to 34 kg/ha with Uran (28-0-0) on all plots by injection through the trickle system.

Injection treatments began the first week of June and ended the last week of July, corresponding to the first full week of harvest. Injections were made twice weekly with 2/3 of the rate applied equally during the first 4 weeks of June and the remaining 1/3 applied during the end of June and the month of July. Injections were made by dissolving the fertilizer for each treatment in 4 liters of water and pumping the solution into the operating trickle irrigation system. Each injection lasted approximately 15 minutes. Following injections, the trickle system was operated for at least 45 minutes.

Harvest began when the first fruit ripened on July 29 and continued until September 4. Early harvest lasted from July 29 until August 5 and would correspond to the period in which a grower would receive the highest market price. Yield was divided into classes of marketable, cracks, green shoulders, and rots. Fruit with more than 2.5 cm of a radial and/or concentric crack was placed in the cracked division; tomatoes having greater than 10% of the upper 1/4 of the ripe fruits surface green at harvest were placed in the green shoulder category, while rots were those fruit experiencing some stage of decay. With the exception of the rots, all categories were sized based on diameter. Small fruits were 5.4 cm, medium fruit were 5.4-6.7 cm and large fruit were >6.7 cm. On September 4, all the remaining immature fruit were harvested and weighed but not categorized or sized.

Internal and external color were measured on approximately 12 large fruit from each treatment using a Hunterlab D25-L9 colorimeter. Internal and external color readings were obtained by placing a 2.5 cm thick slice from the center and the top 1/4 of each fruit, respectively, in the specimen port of the colorimeter. Readings were expressed in terms of an L and an a/b ratio. The "L" component measures lightness and darkness, the "a" component measures redness and the "b" component measures yellowness. The higher the a/b values or hue, the redder the fruit will be.

Samples of the most recently matured leaves were collected on 6/22, 7/13, 8/16 and 8/25 from each plot for plant analysis. Leaves were dried in a forced air drier at 70°C for at least 72 hours and ground in a Wiley mill to pass a 40 mesh screen. Potassium, Ca and magnesium (Mg) concentrations were determined using atomic absorption procedures.

Soil samples 0-15 cm deep were taken following the final harvest. The treatments which received 224 kg K/ha, applied 1/2 broadcast preplant and 1/2 through the trickle system, had samples taken 0-8 cm and 8-15 cm deep, and 8 and 15 cm laterally from the trickle irrigation line. Soil K was determined using the ammonium acetate procedure.

Statistical analysis using the analysis of variance and general linear model procedures compared the effects of the K rate and the method of application on the response variables.

RESULTS

There was no significant interaction between K rate and K application methods or main mean effects for any early yield variable (Tables 1, B1). As fruit size was not influenced by the treatments, and 75% of the fruit were in the large category, size classes were not considered further. Rots were an insignificant component of early yield, accounting for less than 14% of the early total fruit weight, and showed no influence from the K rate or applicaton method.

Table 1. Effect of K rate and application method on early 'Pik Red' tomato yield July 29 to August 5, 1981

	Early yield, mt/ha				
Treatment	Marketable	Cracks	Green shoulders	Rots	Total[a]
K rate kg/ha					
56	7.8	1.3	2.6	1.4	13.2
112	8.3	1.9	3.1	2.1	15.3
224	7.6	0.9	2.7	2.7	13.9
896	9.2	1.9	2.9	1.9	16.0
Appl. method					
BDC[b] preplant	8.2	1.5	2.5	1.9	14.2
½ BDC, plus ½ INJ[c]	8.3	1.5	3.2	2.1	15.0

[a]Total yield is a combination of marketable, cracks, green shoulders and rots.

[b]BDC = broadcast preplant.

[c]INJ = injected through trickle irrigation system.

Most total yield variables did not show a significant interaction between the K rate and method of application (Table B2). Total rot production shows a significant interaction (Figure 1). This interaction is significant because of high rot production (7-8 mt/ha) at the 224 and 896 kg K/ha rate when K is injected, as compared to relatively low rot production (5 mt/ha) when K is applied broadcast preplant at the same rates; but, at the lower 2 K rates, 56 and 112 kg/ha, rot production is 6-8 mt/ha when K is applied broadcast preplant and 4-5 mt/ha when K is injected.

A quadratic trend (P>0.07) is present for marketable yield with the relationship between marketable yield and the K rate explained by the equation $\hat{Y} = 23.78 + 0.014X - 0.000045X^2$, where $\hat{Y}$ is the predicted yield and X is the K rate (Table 2). Solving the first derivative of the equation gives a maximum yield at about 156 kg K/ha.

Applying 1/2 the K through the trickle system significantly (P>0.02) increased by 22% the total weight of green shouldered fruit as compared with applying K broadcast preplant (Table 2). Other measured total yield variables, including immature and cracked fruit, were not influenced by the K rate or application method (Tables B2, 2).

Fruit color was measured in terms of an "a/b" ratio which gives an indication of hue. External color seems unaffected by the K rates (Tables 3, B3). But, the highest K rate, 896 kg K/ha, does cause a much darker red shoulder color as compared with the lower 3 rates (Table 3). Internal color was not affected by the K rate or application method and neither internal nor external color showed a significant interaction between the K rate and application method (Table B3).

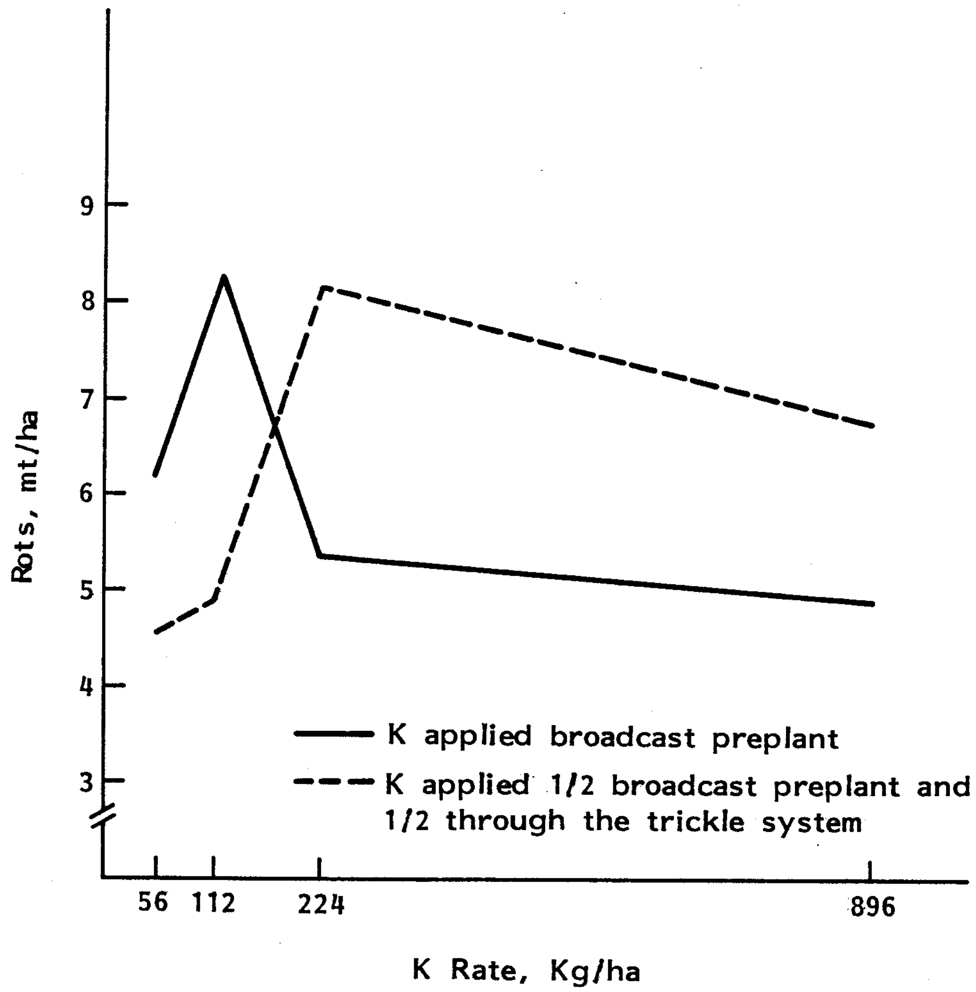


Figure 1. Effect of K rate and application method on total tomato rot yield, 1981

Table 2. Effect of K rate and application method on total 'Pik Red' tomato yield, July 29 to September 4, 1981

Treatment	Yield (mt/ha)					
	Marketable	Cracks	Green shoulders	Immature green fruit	Rots	Total[a]
K rate kg/ha						
56	27.2	11.2	7.0	17.0	5.3	67.8
112	25.0	13.0	7.2	14.5	6.6	66.2
224	31.1	11.2	5.7	15.8	6.8	70.6
896	27.7	13.4	6.3	13.5	5.8	66.7
Prob >F	Q, .07	.24	.20	.97	.49	.87
Application method						
Broadcast preplant	28.3	12.9	5.9	15.0	6.2	68.3
½ BDC[b] + ½ INJ[c]	27.1	11.5	7.2	15.4	6.1	67.3
Prob >F	.45	.14	.02	.97	.93	.87

[a]Total yield is the sum of marketable, cracks, green shoulders, rots and immature green fruit.

[b]BDC = broadcast preplant.

[c]INJ = injected through trickle irrigation system.

Table 3. Effect of K rate and application method on tomato fruit internal and external color

Treatment	a/b ratio means	
	Shoulder color	Internal color
K rate kg/ha		
56	1.07	1.26
112	1.08	1.26
224	1.05	1.15
896	1.29	1.35
Application method		
All BDC[a]	1.05	1.33
½ BDC plus ½ INJ[b]	1.19	1.18

[a]BDC = broadcast preplant.

[b]INJ = injected through trickle irrigation system.

There was no significant interaction between the K application method and the K rate on leaf K percentages. The leaf K percentage increased quadratically with increasing K levels on July 13, August 6, and August 25 (Table B4, Figure 2). There was no difference in the plant K status due to the application method (Table B4). Plant K level declined as the season progressed.

There were no significant interactions between the K application method and the K rate for the leaf Ca and/or Mg levels. Furthermore, the leaf Ca and/or Mg level was not influenced by the K rate or application method on any of the sampling dates. The leaf Ca level was about 2.5% on the first sampling date and rose to nearly 8% on August 6 and then decreased to 4.75% on the last sampling date (Figure 3). Leaf Mg followed a similar

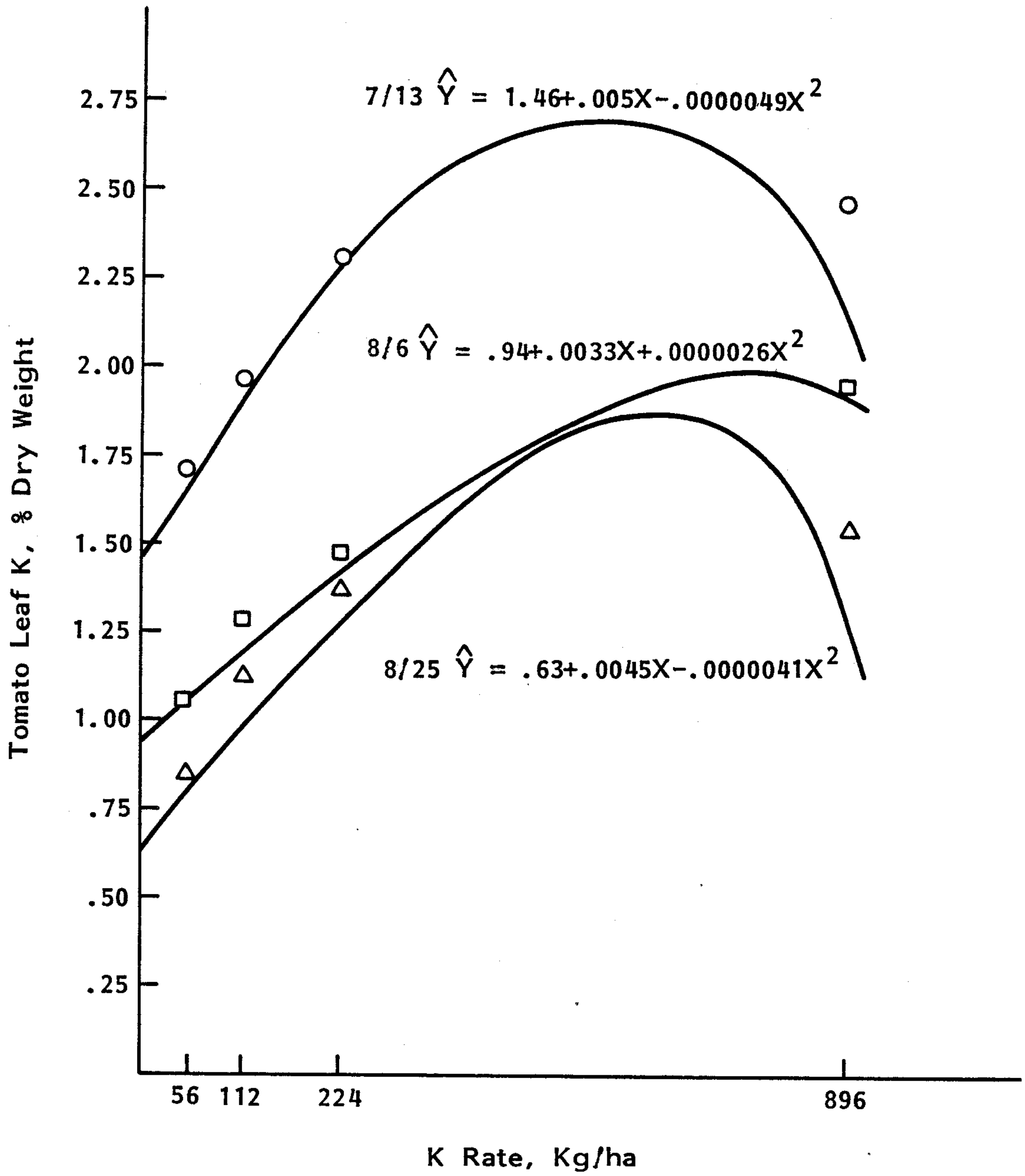


Figure 2. Effect of K rate on tomato leaf K concentration at three sampling dates, 1981

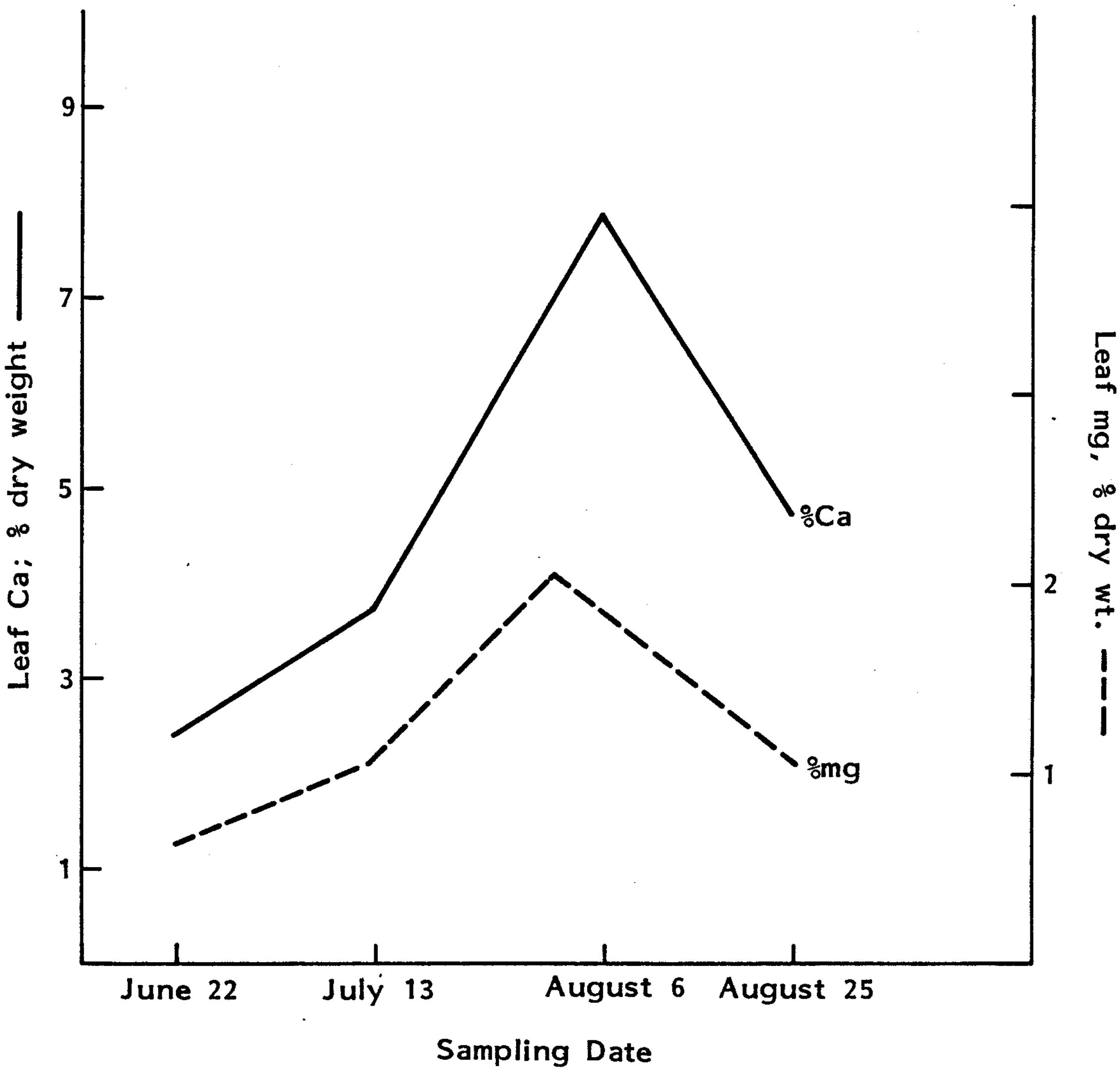


Figure 3. Tomato Ca and Mg tomato leaf concentrations throughout the growing season, 1981

pattern, showing about 1.3% on the first sampling date then increasing to 3.5% on August 5, followed by a drop to 2.3% on August 25.

Residual soil K from those plots which received K as all broadcast preplant was in proportion to the original applied amount (Table 4). Trickle applied K was found to concentrate near the trickle tubing (Table 5). The soil K level decreased sharply on these plots as the sampling depth and distance from the trickle tubing increased.

Table 4. Residual soil K at the conclusion of the growing season

Potassium rate broadcast preplant	Residual soil K (kg/ha)
1. 56	163
2. 112	207
3. 896	315
4. 896	566

Table 5. Soil K at the conclusion of the growing season following application of 224 kg K/ha ½ broadcast preplant and ½ injected into the trickle system

Soil sampling Depth (cm)	Lateral distance from the trickle line (cm)	Residual soil K (kg/ha)
0-7	0-7	809
0-7	7-15	354
7-15	7-15	233
7-15	0-7	383

DISCUSSION

The tomato yield response to applied K on the central Iowa loam soil in this experiment was variable. A quadratic trend ($P>0.07$) was present for maximum total marketable yield at about 156 kg K/ha. This is somewhat consistent with Wilcox (53) who reported maximum marketable tomato yield at about 218 kg K/ha on a silt loam soil which tested low for K. There was no significant effect or trend of K on total yield (combination of marketable, cracks, green shoulders, rots and immature green fruit). Wilcox (53) reported an effect of K rate on total yield, but the magnitude of the K response was less than that for total yield. He found that increasing K tended to increase the quality of the fruit rather than total fruit production; thus, a higher proportion of the fruit from these plots was marketable. This is somewhat consistent with the lack of a total yield response in this experiment.

Although a check or zero rate was not included statistically in the treatment design, there does appear to be a total marketable yield response between the first K level, which yielded 27.2 mg/ha, and the zero rate, which yielded 24.5 mt/ha. Based on these data, it would appear that a maintenance K application should be sufficient for maximum yield on the heavier soils of central Iowa. But, further work should be done on the indeterminate cultivars, which may show a greater K response, before a recommendation can be made.

A difference in the weight of the fruit with green shoulders occurs between application methods (Table 2). Plots which received all broadcast applied K had 22% fewer fruit with green shoulders. But, considering that both application methods supplied plants with equal K, as judged by the leaf analysis, it does not appear that K availability was responsible for the difference. Similarly, the interaction between the K rate and the application method on the total rot weight cannot be correlated to K availability as a result of the treatments (Figure 1). Perhaps some other related factor, such as high salt concentration as a result of K application through the trickle system, is stressing the plants, resulting in more rots at higher K injected rates, as well as more fruit with green shoulders.

The effect of K on tomato quality was also inconsistent. Marketable fruit shoulder color seems to improve (become redder) as the K rate increases. But, most of the improvement is because of a very high shoulder color "a/b" ratio on plots which received 896 kg K/ha. No gradual improvement in shoulder color occurs with an increase in the K rate as has occurred in other investigations (14). In order to gain a better understanding of the effect of K on shoulder color, K rates between 224 and 896 kg K/ha should be included in future investigations. Internal color, which was a darker red than shoulder color, was not influenced by the K rate. Considering that K did not appear to be limiting to tomato yield, it is not surprising that increasing K levels did not have a greater effect on fruit color.

Injection of K through the trickle system did not result in an increase in use efficiency over applying K broadcast preplant. Leaf analysis shows a positive quadratic response to the K rate, but no increase in efficiency when application methods are compared. Perhaps the high soil residual of applied K makes application timing less critical than timing of the more mobile elements such as N. Uriu et al. (50) also applied K through a trickle system on a high CEC soil. They could find no improvement in plant K status over applying dry K near the emitters and drip irrigating. As in this investigation, broadcast applied K was as effective an application method as injection through a trickle system.

The soil samples demonstrate how little the K did move. On plots which received injected K, the majority concentrated near the trickle tubing (Table 5). This is further evidence that K leaching out of the root zone was not a problem and did not limit yield. Furthermore, on high CEC soils, a possible consequence of K injection could be an undesirable K buildup near the trickle tubing, possibly resulting in a deleterious level of soluble salts.

Tomato leaf K levels throughout the growing season were low. Wilcox (53) recommended that, for maximum tomato yield, leaf K levels should be above 2.3% during heavy fruit load. The low leaf K levels in the experiment may in part be due to cultivar selection. 'Pik Red' has a determinate growth habit, whereas the cultivar used by Wilcox (Campbell-146) had an indeterminate growth habit. Lingle and Lorenz (26) reported very low petiole K concentrations in two determinate cultivars regardless of the amount of K applied, whereas indeterminate cultivars, under identical growing conditions, showed no sign of K stress. Direct comparisons between the K status of 'Pik Red' in this experiment and the tomato K status reported by Lingle and Lorenz is not possible. Leaves were sampled in this investigation, whereas Lingle and Lorenz sampled just the leaf petioles. But, the 'Pik Red' tomatoes did show extremely low late-season K levels, similar to the low levels reported by Lingle and Lorez. Very low late-season K levels in determinate cultivars have been associated with their limited root development (53). Perhaps if an indeterminate cultivar would have been used, its larger root system may have been able to utilize increasing K levels and a greater response to applied K would have occurred.

For the most part, the other measured elements (Ca and Mg) were not affected by the K rate or method of application. This agrees with Fong (13), who found the Ca and Mg levels of VF-145 growing in water culture to be independent of the K rate, except in very K-deficient situations. The Ca and Mg accumulation pattern of 'Pik Red' was similar to the Ca and Mg accumulation pattern of Campbell-37 reported by Halbrooks and Wilcox (18), although the percentages of Ca and Mg in 'Pik Red' were very different. 'Pik Red' had a slightly higher Mg level, but the Ca levels showed the most difference. On a comparable sampling date, the 'Pik Red' Ca level approached 8%, almost twice that reported for Campbell-37. The low overall K level of 'Pik Red' may, in part, be related to its high Mg and Ca levels. The K/Ca+Mg ratio reported by Halbrooks and Wilcox (18) was about 1.1 at the beginning of the growing season and dropped to about .49 at the close of the growing season. The K/Ca+Mg ratio of 'Pik Red', contrarily, was about .4 during the first half of the growing season and then dropped to about .25 on the last leaf sampling date. Future work in this area would benefit from more controlled conditions.

One can only speculate as to the effect of K application through a trickle system on coarse textured soils. Potassium movement following application with a trickle irrigation system has approached that of N on sandy soils (23) and an increase in K use efficiency may result under these conditions. But, on the high CEC soils used in the investigation, no advantage in terms of yield or efficiency could be found by injecting the K through the trickle system as compared to preplant broadcasting the required K.

SUMMARY AND CONCLUSIONS

Melons (*Cucumis melo* cv. Burpee Hybrid) were grown on a central Iowa sandy loam soil with clear plastic mulch and trickle irrigation. Four N rates (45, 90, 135 and 180 kg/ha) were applied, either all broadcast preplant or injected through the trickle system according to vegetative growth and development. No apparent N effect on yield occurred, except for a 6 mt/ha increase between the 0 and 45 kg N/ha rate. The N application method did influence melon yield. Total marketable production on those plots which received N broadcast preplant was increased 5 mt/ha over all injected N plots. Petiole NO_3-N indicated trickle applied N supplied more N to the plant early in the growing season. But later in the growing season, the trend was for a higher N status on plots which received N broadcast preplant as compared to all through the trickle system. There would be an economic advantage of applying the N rate all broadcast preplant as compared to all through the trickle system. But, when crops are grown with trickle irrigation, a small amount of N frequently applied early, prior to extensive lateral root development, may be beneficial. If this is not done, broadcast applied N may be moved out of reach of the young crop roots and an early season N stress may result. The amount of N necessary for maximum muskmelon yield in the central part of Iowa when plastic mulch is used is probably about 50 kg/ha.

Tomatoes (cv. Pik Red) were grown on a typical central Iowa loam soil using trickle irrigation. Four K rates (56, 112, 224 or 896) kg/ha were applied either broadcast preplant or ½ broadcast preplant and ½ through the trickle system according to plant growth and development. A quadratic trend was found for maximum marketable yield at about 156 kg K/ha. Most yield variables were not affected by the K application method, although applying the entire K rate preplant did reduce by 22% the weight of green shouldered fruit. Leaf K levels increased quadratically on three of the four sampling dates, but did not differ between application methods. Leaf Ca and Mg were not affected by the K rate, but the leaf Ca was almost twice as high as leaf Ca levels reported in the literature. Trickle applied K was found to concentrate near the trickle tubing and residual broadcast applied K was found in proportion to the original applied rate. External shoulder tomato color improved at the very high K rates, but internal tomato color was unaffected by the K application method or K rate. In conclusion, the K rate needed for maximum 'Pik Red' yield and quality growing on heavy soils testing low to medium for K is probably about 156 kg/ha. There would be no advantage to applying any of the K through the trickle system.

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APPENDIX A.

ANALYSIS OF VARIANCE OF MUSKMELON DATA

Table A1. Analysis of variance for 'Burpee Hybrid' muskmelon yield as affected by N rate and method of application, 1981

Source	df	Early yield mean squares Mkt.[a]	Early yield mean squares Cull	Total yield mean squares Mkt.	Culls	Green fruit	Total	Fruit set	Fruit size
Blocks	3	58.27	8.80	217.1	54.45	18.36	125.8	78.6	0.18
N rate	3	28.50	4.09	81.4	26.50	5.69	51.7	101.6	0.09
Application method	1	232.20	2.35	217.1	3.11	0.59	188.5	300.1*	0.01
N rate*method	3	15.40	6.89	6.7	13.46	16.42	31.7	43.0	0.04
Error	21	55.12	10.14	55.0	9.56	6.04	58.4	57.9	0.12
C.V.		28.7	39.0	19.9	21.9	45.2	14.5	15.1	6.4

[a]Mkt. = marketable fruit production.

*Significant at the .05 level.

Table A2. Analysis of variance for 'Burpee Hybrid' soluble solids, flesh thickness and internal and external appearance as affected by the N rate and application method

Source	df	Mean squares: Soluble solids	Flesh thickness	External width/ length	Melon cavity length	Melon cavity width
Blocks	3	0.38	0.052	0.00075	0.38	0.053
N rate	3	0.13	0.146*	0.00142	0.81	0.76
Application method	1	0.41	0.021	0.00003	1.02	0.19
Method*rate	3	1.57*	0.046	0.00041	0.37	0.17
Error	21	0.46	0.045	0.00094	0.87	0.49
C.V.		9.6	5.6	3.2	8.8	8.8

*Significant at the .05 level.

Table A3. Analysis of variance on three sampling dates for 'Burpee Hybrid' petiole NO_3-N

		Mean squares					
Source	df	June 22	P>F	July 13	P>F	August 3	P>F
Blocks	3	10298228		21487783		4012678	
N rate	3	59575860	.002	17668583	.16	2371318	.04
linear	(1)	149362353	.01	42924617	.05	5490698	.05
quadratic	(1)	938488	<.1	7626886	<.1	1556252	<.1
Application method	1	44452784	.035	32455550	.07	607975	.36
N rate*method	3	10746881	.33	924750	.96	503702	.86
Error	21	8807458		9213480		692592	
C.V.		11.3		41.3		59.2	

APPENDIX B.

ANALYSIS OF VARIANCE OF TOMATO DATA

Table B1. Analysis of variance for early 'Pik Red' tomato yield, July 29 to August 5, 1981

		Mean squares				
Source	df	Marketable	Cracks	Green shoulders	Rots	Total
Blocks	3	2.63	1.88	2.11	3.44	239.11
K rate	3	3.87	1.81	.37	2.34	79.21
Application method	1	.01	.02	3.49	.44	373.09
Rate*method	3	8.23	.14	3.20	1.75	44.95
Error	21	4.97	.53	1.45	1.72	158.98
C.V.		27.1	48.2	42.6	64.7	40.1

Table B2. Analysis of variance for total 'Pik Red' tomato yield, July 29 to September 4, 1981

		Mean squares					
Source	df	Marketable	Cracks	Green shoulders	Rots	Immature green fruit	Total
Blocks	3	3.29	24.66	21.76	21.11	191.78	43.89
K rate	3	51.34	10.73	14.62	3.59	18.09	30.70
Application method	1	55.65	16.36	49.24*	.03	.92	8.11
Rate*method	3	30.30	8.91	13.69	17.29*	94.33	194.71
Error	21	24.06	7.07	8.41	4.30	248.98	283.32
C.V.		15.7	25.6	42.6	33.8	28.05	24.8

*Significant at the .05 level.

Table B3. Analysis of variance for tomato fruit internal and external color

		Mean squares a/b ratios	
Source	df	Shoulder color	Internal color
Blocks	3	0.043	0.073
K rate	3	0.100	0.056
Application method	1	0.149	0.19
Rate*method	3	0.101	0.052
Error	21	0.049	0.099
C.V.		14.07	25.05

Table B4. Effect of K rate and application method on 'Pik Red' tomato leaf K concentration

		Mean squares for leaf K %			
Source	df	June 22	July 13	August 6	August 25
Blocks	3	0.086	0.92**	0.116	0.187
K rates	3	0.090	0.85**	0.947**	0.89**
linear	(1)	0.000	0.161**	2.589**	1.83**
quadratic	(1)	0.242	0.95**	0.244**	0.66*
Appl. method	1	0.009	0.102	0.009	0.038
Method*rate	3	0.149	0.136	0.200	0.15
Error	21	0.079	0.101	0.082	0.098
C.V.		11.64	13.85	14.79	13.74

*,**Significant at the .05 and .01 levels, respectively.